4. Soil Ingestion Rates

4.1 Introduction

Humans may be exposed to airborne chemicals through indirect pathways of exposure. Airborne chemicals may deposit onto soil and pose a risk through incidental or intentional ingestion of contaminated surface soil. This section focuses on the soil ingestion pathway of exposure, and in particular on the default point estimates of soil ingestion rates. This pathway is not a major contributor to the risk for most chemicals in the Air Toxics "Hot Spots" program. However, there are some compounds (e.g., polychlorinated dibenzo-p-dioxins and furans, polycyclic aromatic hydrocarbons, some metals) for which soil ingestion may contribute a significant portion of the total dose and cancer risk estimate.

There is a general consensus that hand-to-mouth activity results in incidental soil ingestion, and that children ingest more soil than adults. Soil ingestion rates vary depending on the age of the individual, frequency of hand-to-mouth contact, seasonal climate, amount and type of outdoor activity, the surface on which that activity occurs, and personal hygiene practices. Some children exhibit pica behavior which can result in intentional ingestion of relatively large amounts of soil.

4.1.1 Incidental Soil Ingestion

Incidental ingestion of soil or dust by adults and children occurs by mouthing hands or objects including food and cigarettes, which have soil on them. Since mouthing is a normal behavior in young children, some soil and dust ingestion can be expected. The potential for exposure via this pathway is greater in young children because hand-to-mouth behavior is frequent, and because on a kilogram body weight basis the amount of soil or dust ingested is greater than in either older children or adults.

4.1.2 Intentional Soil Ingestion

The consumption of nonfood items by young children is a common occurrence. Pica is a behavioral anomaly characterized by the ingestion of nonfood items including soil. It is generally accepted that pica behavior is most prevalent in children three years and younger, and rapidly declines by age six (Barltrop, 1966). A number of authors have reported that not all children with pica ingest soil and that only a subset of pica children ingest greater than average amounts of soil (Barltrop, 1966). Prevalence of soil pica is difficult to estimate because it depends on the definition of soil pica (arbitrarily defined by many as ingestion of greater than one gram soil per day), and because it is an erratic behavior (e.g., children do not consistently eat greater than one gram soil per day). Studies in the literature estimate that between 10 and 50% of children may exhibit pica behavior at some point (Millikan et al., 1962; Cooper, 1957; Barltrop, 1966; Bruhn and Panghorn, 1971; Vermer and Frate, 1979; Sayre et al., 1974; Kanner, 1937; Oliver and O'Gorman, 1966; Stanek and Calabrese, 1995a).

Calabrese and Stanek (1994) reanalyzed four studies of soil ingestion by children and reported that approximately 1.9% of children display pica behavior eating 1 g soil/day, and only about 0.19% ingest up to 10-13 g soil/day. Higher estimates of frequency of soil pica behavior from a later analysis by Stanek and Calabrese (1995a) are presented in section 4.6. Children exhibiting soil pica are a sensitive subpopulation at greater risk from exposure via the soil ingestion pathway.

4.2 Current CAPCOA Algorithm for Dose from Soil Ingestion

Currently, the algorithm used in the Air Toxics "Hot Spots" program (see CAPCOA, 1993) for estimating dose from soil ingestion is as follows:

$$\text{Dose} = \frac{\text{Csoil} \times \text{Isoil} \times \text{GI} \times \text{Bio} \times 10^{-6}}{\text{BW} \times 10^{3}} \qquad \text{(Eq. 4-1)}$$

where:

Dose = dose through soil ingestion (mg/kg body weight-day)
Csoil = concentration of contaminant in soil (μg/kg soil)
Isoil = lifetime average soil ingestion rate
GI = gastrointestinal absorption fraction if different from study used for toxicity criteria; unitless
Bio = bioavailability; unitless
1×10^{-6} = conversion factor (kg/mg)
BW = body weight (kg)
1×10^{3} = conversion factor (μg/mg)

OEHHA is recommending the same basic algorithm with the modifications discussed below. In particular, GI and Bio are being merged into one factor, termed the gastrointestinal relative absorption factor or GRAF. In addition, separate point estimate soil ingestion rates are being proposed for children and adults.

4.3 Proposed Algorithm for Dose via Soil Ingestion

4.3.1 Inadvertent Soil Ingestion by Adults

The dose from inadvertent soil ingestion by adults can be estimated using the following general equation:

$$\text{Dose} = \frac{\text{Csoil} \times \text{GRAF} \times \text{SIR} \times \text{EF} \times \text{ED} \times 10^{-9}}{\text{AT}} \qquad \text{(Eq. 4-2)}$$

where:

Dose = dose from soil ingestion (mg/kg body weight-day)
1×10^{-9} = conversion factor (μg to mg and kg to mg)
Csoil = concentration of contaminant in soil (μg/Kg soil)
GRAF = gastrointestinal relative absorption fraction, unitless; chemical-specific

SIR = soil ingestion rate (g/kg BW-day)
EF = exposure frequency (days/year), EF = 350 d/yr
ED = exposure duration (years)
AT = averaging time, period of time over which exposure is averaged (days); for noncancer endpoints, AT = ED $\times$ 365 d/yr; for cancer risk estimates, AT = 70 yr $\times$ 365 d/yr = 25,550 d

In this approach, it is assumed that the soil ingested contains a representative concentration of the contaminant(s) as modeled by the deposition model, and that the concentration is constant over the exposure period.

The term GRAF, or gastrointestinal relative absorption factor, is defined as the fraction of contaminant absorbed by the GI tract relative to the fraction of contaminant absorbed from the matrix (feed, water, other) used in the study(ies) that is the basis of either the cancer potency factor (CPF) or the reference exposure level (REL). If no data are available to distinguish absorption in the toxicity study from absorption from the environmental matrix in question, soil in this case, then GRAF = 1. The GRAF allows for adjustment for absorption from a soil matrix if it is known to be different from absorption across the GI tract in the study used to calculate the CPF or REL. At present that information is available only for polychlorinated dibenzo-p-dioxins and dibenzofurans. The GRAF for those compounds is 0.43. All others have a GRAF of 1.

4.3.2 Inadvertent Soil Ingestion by Children

As described in section 4.7, children have been divided into the following age groups with respect to soil ingestion rate: 1 through 6 years of age, and 7 to 18 years. Separate point estimates of soil ingestion rates are used for these age groups. In Section 4.7, OEHHA recommends soil ingestion rates for the 9, 30 and 70 year exposure duration scenarios suggested in Chapter 11. The exposure duration scenarios evaluate the first 9, 30 and 70 years of an individual's life. OEHHA is recommending that 18 kg be used for the body weight for the 0-9 year exposure duration determination of dose from soil ingestion (Chapter 10). For the 30 and 70 year exposure duration scenarios, OEHHA recommends that 63 kg be used for the body weight term (Chapter 10). These body weights have been incorporated into the recommended soil consumption rates (mg/Kg BW-day). Care should be taken in using the appropriate ED and EF values for each sub-age grouping as well as the appropriate AT. Pica children are analyzed separately as described in Section 4.7.

4.3.3 Inadvertent Soil Ingestion by Offsite Workers

When the zone of impact of a facility includes offsite workplaces, risk estimates for those offsite workers includes exposure from incidental soil ingestion for multipathway chemicals. Equation 4-2 can be used; however, the exposure is adjusted for the time at work by multiplying by 8/24 hours, 5/7days, 50/52 weeks, and 46/70 years (a total adjustment of 0.15). This adjustment is meant to account for soil ingestion occurring while at work. The assumption inherent in the exposure adjustment is that one third of the daily soil ingestion occurs at work. It may be an underestimate for those who work outdoors at the receptor location, and an overestimate for those who work indoors.

4.4 Soil Ingestion Studies

Soil ingestion data from the draft U.S. EPA Exposure Factors Handbook (1995, 1997), the American Industrial Hygiene Council (AIHC) Exposure Factors Sourcebook (1994), and several peer-reviewed journal articles were analyzed for applicability to estimating point estimate values and distributions of soil ingestion rates for children and adults. Analysis of the literature indicated that in general, two approaches to estimating soil ingestion rates were taken. The first method involves measuring the dirt present on an individual's hand and making generalizations regarding exposure based on observation of hand-to-mouth activity. Results of these studies, conducted prior to 1985, are associated with large uncertainty due to their subjective nature. We have not presented these studies in this document. The other method of estimating soil ingestion rates involves measuring the presence of non-metabolized tracer elements in the feces of an individual and soil with which an individual is in contact. These studies are discussed below.

4.4.1 Studies in Children

4.4.1.1 Binder et al. (1986)

These investigators measured tracer elements in feces to estimate soil ingestion by young children. Soiled diapers collected over a three day period from 65 children (42 males and 23 females) one to three years of age, and composite samples of soil obtained from 59 of these children's yards were analyzed for aluminum, silicon, and titanium. It was assumed that the soil ingested by these children originated largely from their own yards. The soil tracer elements were assumed to be minimally absorbed in the GI tract and minimally present in the children's diet. Soil ingestion by each child was estimated based on an assumed fecal dry weight of 15 g/day, using the three tracer elements. Tracer elements were assumed to be neither lost nor introduced during sampling. The investigators obtained soil ingestion rates by dividing the product of mg tracer per gram feces and fecal dry weight in g/day by the concentration of that tracer in the soil. Daily soil ingestion based on aluminum and silicon and titanium are presented in Table 4.1. The minimum soil ingestion presented in the table is based on the lowest of three estimates of soil ingestion in each subject. The minimum is presented because of the failure to account for the presence of the three tracers in ingested foods, medicines, and other sources such as toothpaste. Estimates from aluminum and silicon were comparable; however, much higher soil ingestion estimates were obtained using Ti as a tracer. Binder et al. (1986) report that there may have been an unrecognized source of Ti that children were ingesting.

Table 4.1 Soil ingestion rates (mg/day) from Binder et al. (1986)

Tracer:	Al	Si	Ti	Minimum
Mean	181	184	1834	108
Std Dev	203	175	3091	121
Range	25-1324	31-799	4-17,076	4-708
Median	121	136	618	88
95th percentile	584	578	9590	386
geo mean	128	130	401	65

The advantages of this study include a relatively large sample size and use of the less-subjective tracer method in contrast to previous studies based on observation of mouthing behavior. However, there were several methodological difficulties with the protocol pointed out by Binder and colleagues. The tracers ingested in foods and medicines were not accounted for which leads to overestimation of soil ingestion rates. Rather than using measured fecal weights, the investigators assumed a dry fecal weight of 15 g/day for each child. Measuring fecal weights was difficult because the entire diaper (including urine) was collected, and as much stool as possible recovered from the diaper. The investigators used data on stool production by 13 to 24 month old children from a previous study to arrive at the 15 g/d estimate. This may lead to either over- or underestimation of soil ingestion rates. This was a short-term study and, as with all the studies on soil ingestion rates, the data may not be entirely representative of longer-term soil ingestion rates. Finally, the children may not be a representative sample of the U.S. population.

4.4.1.2 Clausing et al. (1987)

In a pilot study, fecal samples from 18 Dutch children ages two to four years attending a nursery school, and samples of playground soil at the school were analyzed for Al, Ti, and acid insoluble residue (AIR) content. Twenty-seven daily fecal samples were obtained over a five-day period while the children were at school. Stool produced outside of school hours was not collected. Soil ingestion was estimated using each tracer from average concentrations in the school yard soil and assuming a dry fecal weight of 10 g/day. These investigators also collected eight daily fecal samples from a group of six hospitalized bedridden children with no access to soil to use as a control group.

The investigators based their estimates of soil ingestion on the Limiting Tracer Method. In this method, the maximum amount of soil ingested by each subject corresponds to the lowest estimate from the tracers used. The method tends to bias in the negative and may underestimate soil ingestion rates. The mean from this study of 56 mg/day was calculated as the mean for the schoolchildren minus the mean for the control hospitalized children (Table 4.2).

The advantages of the Clausing study are that soil ingestion was evaluated in two groups of children, one serving as a control. There are several disadvantages of this study for our purposes. The food and medicine taken by the children were not analyzed for the content of tracer elements. Stool produced during non-school hours was not collected. The Limiting Tracer

Method likely underestimates soil ingestion rates. As with other studies, a short-term study of soil ingestion rates may not be representative of longer term soil ingestion rates. Finally, the small sample size results in statistical instability, and the Dutch children sampled may not be representative surrogates for the U.S. population.

Table 4.2 Soil ingestion results (mg/day) from Clausing et al. (1987)

	School Children	**Hospitalized Children**	**Difference**
mean	105	49	**56**
std dev	67	22	
range	23-362	26-84	
geo mean	90	45	

4.4.1.3 Van Wijnen et al. (1990)

Soil ingestion by children in four different environments (day care with and without gardens, campgrounds, hospitals) was evaluated using the Limiting Tracer Method. Fecal samples and soil samples from the play areas were collected and analyzed for Ti, Al and AIR (acid insoluble residue). Ti and Al were analyzed by inductively-coupled plasma-atomic emission spectrometry. Using an assumption of 15 g dry weight feces/day, and assuming minimal absorption of tracers, soil ingestion rates were calculated as the product of the concentration in feces and the amount of feces produced divided by the concentration of tracer in soil.

These investigators used the hospitalized children as a control group. The 95% confidence limit of the mean soil ingestion value was subtracted from the mean soil ingestion values obtained from the other groups. The investigators present a number of soil ingestion rates in the paper. Geometric mean soil ingestion rates ranged from 0 to 90 mg/day for day-care center children, and 30 to 200 mg/day for children at campgrounds.

This study sampled a number of children in several different environments. However, for our purposes there are several disadvantages. Tracer content of food and medicines was not evaluated. The Limiting Tracer Method tends to underestimate soil ingestion rates. The relatively small sample size per group and the short-term nature of the study are also limiting.

4.4.1.4 Davis et al. (1990)

A mass balance approach was used to evaluate soil ingestion in a random sample of 104 toilet-trained children between two and seven years of age studied over a seven-day period in the summer in southeastern Washington. The Al, Si, and Ti contents of foods, feces, urine, soil and house dust from each child’s home were analyzed using x-ray fluorescence spectrometry. Soil intake rates were corrected for the amount of tracer in vitamins and medicines.

The results (Table 4.3) indicate a large degree of variability. The means for aluminum, silicon and titanium as tracers were 39, 82, and 246 mg/d, respectively. The investigators in reporting the range include negative numbers. This is indicative of a basic difficulty in estimating soil ingestion rates in a mass balance approach. If fecal output does not correspond to the food/medicines sampled due to variation in transit time in the gut, then the calculation of soil ingestion rate will be inaccurate. Overcorrecting for the presence of tracer in foods and medicines can bias the soil ingestion estimates downward, producing negative soil ingestion estimates which are obviously impossible. Likewise, if the food that was digested to produce the fecal sample contained more tracer than the food that was sampled, the soil ingestion rate can be biased in the positive. While this study's strengths include evaluation of demographic and behavioral information with respect to soil ingestion, the negative soil ingestion estimates are problematic.

Table 4.3 Soil ingestion results from Davis et al. (1990), mg/day

	Aluminum	Silicon	Titanium
Mean	38.9	82.4	245.5
Median	25.3	59.4	81.3
Std Error	14.4	12.2	119.7
Range	-279 to 903	-404 to 534.6	-5820 to 6182

4.4.1.5 Calabrese et al. (1989)

This study based estimates of soil ingestion rate on measurements of eight tracer elements (aluminum, barium, manganese, silicon, titanium, vanadium, yttrium, and zirconium) using a method similar to Binder et al. (1986) but including a mass balance approach, and evaluating soil ingestion over eight days rather than three days. The study population consisted of 64 children between one and four years old in the Amherst, Massachusetts area. Duplicate meal samples, including vitamins and medicines, were collected for all children from Monday through Wednesday of two consecutive weeks, while fecal and urine samples were collected over four 24-hour periods from noon Monday through noon Friday in the corresponding weeks. Soil and dust samples were collected from each child's home and play areas. Children were given toothpaste, diaper rash ointment and other hygiene products that contained trace to no levels of tracer elements. Blanks of diaper and commode specimens using distilled water were collected to control for introduced tracer. Samples were analyzed for tracer content by inductively coupled plasma atomic-emission spectrometry following sample treatment. Care was taken to avoid contamination of food and waste samples with the eight tracers. Waste samples from a single 24-hour period were pooled into one sample for analysis. Soil samples represented composite samples from the three areas in which the child played the most.

In addition to the study of soil ingestion by children, these investigators also present a validation study in adults. Six volunteers, ages 25-41, ingested empty gelatin caps at breakfast and dinner on Monday, Tuesday, and Wednesday of week one, gel caps containing 50 mg sterilized soil at breakfast and dinner Monday, Tuesday, and Wednesday of week two, and gel caps containing 250 mg soil at breakfast and dinner Monday, Tuesday, and Wednesday of week three. Duplicate food samples were collected as in the children's study and total excretion was collected Monday through Friday for the three study weeks. Soil was determined to be non-contaminated in terms of priority pollutants and contained enough of each tracer to be detectable in the excreta.

The adult validation study indicated that study methodology could adequately detect soil ingestion at rates expected by children. The ingestion of 300 mg soil in the second week was accompanied by a marked increase in fecal excretion of tracer that could not be accounted for by variability of tracer in food. Recovery data from the adult study indicated that Al, Si, Y, and Zr had the best recoveries (closest to 100%) while Mn and Ba grossly exceeded 100% recovery. Both these elements are unreliable due to their relatively higher concentrations in food relative to soil. Zirconium as a tracer was highly variable and Ti was not reliable in the adult studies. The investigators conclude that Al, Si, and Y are the most reliable tracers for soil ingestion.

The results of the soil ingestion calculations for children based on excretory tracer levels minus food tracer levels (Table 4.4) indicate a median value between 9 mg/day for yttrium and 96 mg/day for vanadium. There was a large degree of interindividual variation, with one or two extreme outliers. The mean estimates were considerably higher than the median in most cases.

Table 4.4 Soil Ingestion Results For Children Aged 1 To 4 Years From Calabrese Et Al. (1989) In Mg/Day

	Al	Si	Ti	V	Y	Zr
Mean	153	154	218	459	85	21
Median	29	40	55	96	9	16
SD	852	693	1150	1037	890	209
P95th	223	276	1432	1903	106	110
Max	6837	5549	6707	5676	6736	1391

This study is useful in several ways. The mass balance approach attempts to correct for ingestion of tracer such as Ti in foods, medicines, and toothpaste. The validation regimen in adults points out the most reliable tracers and validates the overall methodology. The complete sample collection of urine and feces in this study obviates the need to assume a fecal weight for calculating soil ingestion estimates.

One child in this study exhibited pica behavior. The high soil ingestion rates for this child may or may not be applicable to other soil pica children or, over time, even to this one child. However, it is interesting to note that this study did pick up a child with this behavior.

4.5 Studies in Adults - Calabrese et al. (1990)

Although inadvertent soil ingestion by adults is recognized as a pathway of exposure to environmental contaminants, only one preliminary study quantifying soil ingestion in adults has been published. This study was originally part of the study in children published in 1989, and the methodology is described above in section 4.4.1.5. The soil ingestion rates for the 6 volunteer adults was estimated by subtracting out the tracer quantities in food and soil capsules from the amounts excreted. The four most reliable tracers were Al, Si, Y, and Zr. Median soil ingestion rates were as follows: Al, 57 mg; Si, 1 mg; Y, 65 mg; and Zr, -4 mg. Mean values were: Al, 77 mg; Si, 5 mg; Y, 53 mg, and Zr, 22 mg. The average of the soil ingestion means based on the four tracers is 39 mg. The preliminary nature of these data should be emphasized. The sample size is very small (n = 6). The study was not designed to look at soil ingestion by the adults but rather as a validation of the overall methodology.

4.6 Distributions of Soil Ingestion Estimates

4.6.1 Thompson and Burmaster (1991)

Thompson and Burmaster reanalyzed the original data from Binder et al. (1986) to characterize the distribution of soil ingestion by children. Soil ingestion estimates from Binder's study using Al and Si tracers were adjusted using actual stool weights measured in the original study instead of the assumed stool weight of 15 g/day. Ti was not used because the data could not be adjusted for presence of Ti in foods. Thompson and Burmaster reported that soil ingestion rates in children are lognormally distributed. They obtained lower soil ingestion rates than reported in Binder et al. (1986) attributable to use of the actual fecal weight data. Based on Al and Si tracers, Thompson and Burmaster report a mean of 91 mg/day, and a 90th percentile of 143 mg/day (Table 4.5). Use of actual fecal weight data may be construed as an improvement over the estimates in the original paper. However, difficulties in obtaining stool weights by the original investigators makes an adjustment questionable. In addition, the original Binder study has several methodological difficulties and there are newer data available using a mass balance approach. As with most soil ingestion studies, no discussion of pica children is included in the original study or in this reanalysis.

Table 4.5 Distribution Of Soil Ingestion Estimates For Children Presented By Thompson And Burmaster (1991); Data From Binder Et Al. (1986) Expressed In Mg/Day

Mean	91
Standard Deviation	129
Median	59
90th percentile	143

4.6.2 AIHC (1994) and Finley et al. (1994)

The AIHC Exposure Factors Sourcebook presented several distributions for children's soil ingestion rates including that of Thompson and Burmaster discussed in the previous section. AIHC-derived distributions were limited to data from zirconium (Zr) as a tracer in Calabrese et al. (1989) and Calabrese and Stanek (1994). Since various tracer elements give divergent soil ingestion estimates, it may not be valid to pick one tracer out of the eight used in the studies. Zr consistently gave relatively low estimates.

AIHC presents a distribution of soil ingestion estimates for adults based on a preliminary study by Calabrese et al. (1990). AIHC chose the data based on Zr as a tracer. The distribution presented by AIHC has a median value of 0 mg/day, and a maximum value of 216 mg/day. Since the Calabrese data are preliminary, it is premature to characterize the distribution of soil ingestion estimates using a single tracer from this study.

Finley et al. (1994) also constructed distributions based on the Zr data in Calabrese et al. (1989). The distribution was constructed using negative soil ingestion estimates for the 5th percentile (-70 mg/day), and the 10th percentile (-35 mg/day). The authors then truncated the distribution at 0 mg/day which was approximately the 36th percentile. Based on discussion in Sections 4.6.3 and 4.6.4 below, OEHHA does not recommend using the distribution in Finley et al. (1994) for stochastic modeling. The truncation of the distribution does not mitigate the problem of using negative numbers to construct the distribution. In addition, the validity of using only one element, Zr, from the dataset is questionable.

4.6.3 Stanek and Calabrese (1995a)

Stanek and Calabrese (1995a) reanalyzed the soil ingestion study by Calabrese et al. (1989). These investigators constructed daily soil ingestion estimates using food and fecal trace-element concentrations from Calabrese et al. (1989), and reported a soil ingestion distribution developed from data adjusted to in part account for problems associated with tracer selection in determining soil ingestion rates. A distribution of daily soil ingestion estimates, assumed to be lognormal, was constructed from the short-term study by extrapolating over 365 days. All soil ingested was assumed to come from outdoors.

There are a number of methodological difficulties in attempting to quantify soil ingestion. Food (and vitamins, medicines), soil, and fecal material are analyzed for specific tracer elements in a mass balance approach to soil ingestion estimates. The assumption implicit in analyzing food and feces for the tracer elements and in the calculation used to estimate soil ingestion is that the feces represents that formed from the food/medicines analyzed. However, transit time through the gut varies widely. The fecal sample may not represent the food/medicine sample. This input-output misalignment can underestimate soil ingestion even resulting in negative soil ingestion estimates. The other main type of error in tracer studies for estimating soil ingestion is source error. Source error occurs when an unknown or unaccounted for source of the tracer element is ingested by the study subjects. The soil ingestion estimate can be inflated since it is assumed that soil is the source of tracer.

Stanek and Calabrese (1995a) adjust the data from Calabrese et al. (1989) in a number of ways in order to generate a soil ingestion rate distribution. The issue of directly connecting food intake with fecal output arises (input-output misalignment). Stanek and Calabrese (1995a) in reconstructing soil ingestion estimates link the passage of food to feces by assuming a food transit time of 28 hours. This allows adjustment of soil ingestion rates for days when food samples were not taken the day prior to collection of feces (e.g., on Mondays and Fridays in the initial Calabrese study protocol). Further adjustments are made to account for days in which there was no fecal output; these adjustments link foods consumed prior to the day with the missing fecal sample to subsequent days' fecal outputs. Daily soil ingestion estimates were made for each element and each study subject from Calabrese et al. (1989) data. For each day and subject, medians, and lower and upper bounds of soil ingestion rate were calculated for the eight tracers. The lower and upper bounds of soil ingestion estimates are based on a "relative standard deviation" which incorporates judgment about the relative precision of a soil ingestion estimate based on the detection limit from a given tracer. The lower and upper bounds functioned as exclusion criteria. If a soil ingestion rate estimate fell outside the bounds, it was assumed to be invalid and discarded. The median of the remaining trace element estimates was defined as the best estimate of soil ingestion for the day for the subject. Estimates of soil ingestion could not be made for everyone for all eight days because of missing fecal samples. In addition, a given soil ingestion estimate is not necessarily based on all tracers studied because estimates that exceeded the outlier criteria were excluded. Thus, the number of days per subject with soil ingestion estimates ranged from four to eight, and the number of elements used per day to estimate soil ingestion for a given subject varied from one to eight. The investigators took both a mean and median of each subject's daily soil ingestion estimates. Cumulative distributions of the means and the medians were constructed. The results indicate that mean soil ingestion estimates over the study period of four to eight days were 45 mg/day or less for 50% of the children and 208 mg/day or less for 95% of the children. The median daily soil ingestion estimates were 12 mg/day or less for 50% of the children studied, and 138 mg/day or less for 95% of the children studied.

The investigators also used the daily soil ingestion rate estimates to create a distribution of soil ingestion rates extrapolated over a year. The daily soil ingestion estimates, representing the median or mean of any tracers not excluded on a given day, were used to characterize a distribution of values for 365 days assuming a lognormal distribution for each subject (Table 4.6). Negative estimates were replaced with a value of 1 mg/day. Order statistics corresponding to z scores for percentiles in increments of 1/365 were used with the assumption of lognormal distribution to form soil ingestion estimates for 365 days for each subject. The median of the distribution of average daily soil ingestion (average of estimates from different tracers in a day) predicted over 365 days is 75 mg, while the 95th percentile is 1751 mg/day (Table 4.6). The median of the distribution of median soil ingestion estimates is 14 mg/day while the 95th percentile is 252 mg/day. Soil ingestion rates vary widely; the range of upper 95 percentiles of the median soil ingestion rate estimates for 63 kids (exclusive of the one pica child) is 1 to 5623 mg/day.

Table 4.6 Soil Ingestion Distributions From The Stanek And Calabrese (1995a) Reanalysis Of Calabrese Et Al. (1989) Data - Fitting Lognormal Distribution To Daily Average (Row 1) Or Daily Median (Row 2) Soil Ingestion Estimates For 64 Individuals Extrapolated Over 365 Days

	Range	Median	90th%	95th%
Average daily soil ingestion rates for 64 subjects	1 - 2268 mg/day	75 mg/day	1190 mg/day	1751 mg/day
Median daily soil ingestion rates for 64 subjects	1-103 mg/day	14 mg/day	--	252 mg/day

Stanek and Calabrese (1995a) also evaluated the presence of soil pica using the distribution developed from their adjusted soil ingestion rates. An estimated 16% of children are predicted by this method to ingest more than 1 gram of soil per day on 35-40 days of the year. In addition, 1.6% would be expected to ingest more than 10 grams per day for 35-40 days per year.

Table 4.7 Estimates Of Percent Of Children Exceeding The Given Soil Ingestion Rates For Specified Number Of Days Per Year From Stanek And Calabrese (1995a)

	Days per year of excessive soil ingestion		
Soil Ingestion Rate	1-2	7-10	35-40
> 1 gram	63	41	16
> 5 grams	42	20	1.6
>10 grams	33	9	1.6

The advantages of Stanek and Calabrese (1995a) include a thorough reanalysis of the data in Calabrese et al. (1989) which itself is one of the most thorough studies of soil ingestion rates published. The Stanek and Calabrese report attempted to link the food samples with the fecal samples to more accurately estimate soil ingestion rates. In addition, the tracers were ranked according to usefulness, and criteria for excluding a soil ingestion estimate were incorporated into their reanalysis.

There are some methodological problems with the development of the distribution of soil ingestion rates that affect the usefulness of the distribution. The transit time in the gut was assumed to be the same for all subjects and not to vary within subjects. Thus, the correction for transit time is itself uncertain and may not adequately correct for input-output misalignment error. Indeed, negative soil ingestion estimates were still obtained; the authors replaced them with a soil ingestion estimate of 1 mg/day for characterizing the distribution. Nonetheless, making the assumption about transit time in order to link food and fecal samples better leads to more accurate soil ingestion rate estimates than ignoring transit time altogether. Longer-term studies would be useful to obviate the need for adjusting for transit time.

The outlier criterion used to eliminate element-specific estimates for individual subject days itself contains some judgments and assumptions regarding the relative accuracy of the tracers to detect soil ingestion, and the method is unique. The technique was employed to attempt to correct for the likelihood that ingestion of some tracers from sources other than food or soil occurred. There are large discrepancies between individual tracer elements' estimates of soil ingestion for the same subject on the same day. While we are critical of some aspects of their exclusion methodology (using the median as a reference point rather than the mean, no indication of how many data points were excluded or what those data points were), the effect of these exclusions is actually fairly small as indicated by comparing the distributions of the mean estimates when three or fewer elements are used following exclusion with the distribution of the mean estimates where no elements are excluded (Table 6 in Stanek and Calabrese, 1995a).

The annual soil ingestion distribution generated in the paper and presented in Table 4.6 is assumed to be lognormal. It is based on individual lognormal distributions for each of the 64 subjects generated by applying order statistics to soil ingestion estimates for each subject to generate 365 daily soil ingestion estimates for each subject. The assumption that the distribution of soil ingestion estimates over a year is lognormal for any individual is plausible, yet there are no data to support its use since there are only between four and eight estimates of the soil ingestion rate for each of the 64 individuals. Therefore estimates of the mean and variance of the lognormal distribution have large variance. This results in large variability in the annual soil ingestion estimates, and contributes to uncertainty. As with all studies, the relatively short duration of the study introduces uncertainty when extrapolating the results out to a year. It is not possible to ascertain from the studies available in the literature whether the variability in soil ingestion measured over four to eight days reflects the variability in soil ingestion rate over 365 days.

The nonrandomly sampled population (educated community in a college town) may not be representative of the U.S. population, and soil ingestion behavior may be affected by socioeconomic factors not present in this study population.

4.6.4 Stanek and Calabrese (1995b)

Stanek and Calabrese published a separate reanalysis combining the data from their 1989 study with data from Davis et al. (1990) and using a different methodology from that in Stanek and Calabrese (1995a). This methodology, the Best Tracer Method (BTM), is designed to overcome intertracer inconsistencies in the estimation of soil ingestion rates. The BTM involves ordering of trace elements for each subject based on the food:soil ratio. Tracers with a low food:soil ratio lead to more precise soil ingestion estimates because confounding from the tracer content of food is decreased. Available data from Calabrese et al. (1989), Calabrese et al. (1990), and Davis et al. (1990) soil ingestion studies were used to construct estimates of the food:soil (F/S) ratio for each trace element for each subject/week. Note that F/S ratios will vary from one subject to the next and week to week because it depends on what the subjects have eaten. The F/S ratio was calculated by dividing the average daily amount of a trace element ingested from food by the soil trace element concentration per gram soil. For each subject/week, these ratios were ranked lowest to highest. Distributions of soil ingestion estimates are presented based on the various ranked tracers for both children and adults from all three studies. In addition, data from the Davis et al. (1990) and Calabrese et al. (1989) studies on soil ingestion in children were combined to form another distribution. In contrast to the Stanek and Calabrese (1995a) distribution, negative values for soil ingestion estimates were included in the distributions in this paper. This would shift the distribution towards lower ingestion estimates. While it is valuable to eliminate source error as much as possible by utilizing elements with low F/S ratios, the presence of negative soil ingestion estimates is indicative that there still is a problem with input-output misalignment. Negative soil ingestion estimates are biologically meaningless, and incorporating these values into a distribution is problematic. Distributions of soil ingestion estimate from the combined studies for children are presented in Table 4.8.

Table 4.8 Distributions Presented In Stanek And Calabrese (1995b) In Mg/Day

	50th%	**90th%**	**95th%**	**99th%**	**Ave ± SD**	**Sample Max**
Calabrese 89[a]	33	110	154	226	132 ± 1006	11,415
Davis 1990[b]	44	210	246	535	69 ± 146	905
Combined	37	156	217	535	104 ± 758	11,415

a. Data from Calabrese et al., 1989
b. Data from Davis et al., 1990

4.6.5 Summary of Utility of Existing Distributions to Air Toxics "Hot Spots" Program

The Calabrese et al. (1989) and Davis et al. (1990) data are the best available on soil ingestion in children. There are difficult methodological issues in estimating soil ingestion and in analyzing and interpreting soil ingestion data from different tracer elements. Stanek and Calabrese (1995a and 1995b) address these difficulties in their paper, acknowledge the uncertainties in their methods and attempt to ascertain the impact of these uncertainties on the distributions developed from their reanalysis of the Calabrese et al. (1989) data and the analysis of Davis et al. (1990) data. The distributions presented in the two Stanek and Calabrese papers (1995a and b) are very different. It is not possible given the existing studies to ascertain which of these distributions is more appropriate to use for site-specific risk assessments. At this time, OEHHA is not recommending a distribution for use in the Air Toxics "Hot Spots" program pending resolution of the various problems associated with estimating soil ingestion rates and characterizing an appropriate distribution. New studies are on the horizon and it is appropriate at this time for this program to wait until more data become available.

4.7 Recommendations

4.7.1 Incidental Soil Ingestion by Children

The U.S. EPA (1989, 1991) uses 200 mg/day as a soil ingestion rate for children one through six years of age. In their 1997 update of the Exposure Factors Handbook, U.S. EPA recommends 100 mg/day as a mean for children under six, but indicates 200 mg could be used as a conservative estimate of the mean as it is consistent with the data. For children seven to 18 years and for adults, U.S. EPA (1989, 1991) uses 100 mg/day as a soil ingestion rate. However, in the 1997 update U.S. EPA indicates that 50 mg/day is still a reasonable estimate for adults, although no new data became available to them to cause a shift in the assumption. Since the data are limited all around, OEHHA recommends using 200 mg/day for children through age six and 100 mg/day for everyone older than six including adults and dividing by the time-weighted average body weight for 0-9 years and 0-70 years. Development of a distribution may become more reasonable with further research. OEHHA is recommending using 8.7 mg/kg-day for the 0 to 9 year exposure scenario and 1.7 mg/kg-day for the 30- and 70-year exposure scenarios. For the 9-year scenario, the soil ingestion rate estimate is derived by taking (6/9 x 200 mg/day + 2/9 x 100 mg/day) and dividing through by a time-weighted average body weight of 18 kg for 0-9 years. The recommendation for 30 and 70 years is derived by talking (6/70 x 200 mg/day + 63/70 x 100) and dividing by the time-weighted average body weight of 63 kg for age 0 to 70. It would be possible to generate a separate soil ingestion point estimate for 30 years but in the interest of simplicity it was decided to recommend that the time weighted average for 70 years also by used for 30 years. OEHHA recommends using these numbers (Table 4.9) in a point estimate approach to calculate soil ingestion dose and risk for Tiers 1 through 4 risk assessments.

4.7.3 Incidental Soil Ingestion by Adults

Lack of data in adults makes the development of soil ingestion rates for individuals greater than 18 years of age very difficult. The preliminary data of Calabrese et al. indicate a soil ingestion rate of 39 mg/day for the six volunteers which is less than the current U.S. EPA value of 100 mg/day. Since the data are preliminary, as noted above OEHHA suggests adopting the current U.S. EPA estimate of soil ingestion rate of 100 mg/day for people seven years and older. In addition OEHHA does not currently recommend using the preliminary data of Calabrese et al. (1990) to develop a distribution of soil ingestion rates in adults. Development of a distribution awaits further research on soil ingestion.

4.7.4 Intentional Soil Ingestion (Pica) by Children

It may be appropriate in some risk assessments to separately evaluate the risk to pica children. These children represent a sensitive subpopulation because of their high soil ingestion rates. Stanek and Calabrese (1995a) provide information on soil pica frequency and approximate ingestion rates for those children (Table 4.7). The risk assessor should choose values from Table 4.7 to create a soil pica scenario for children under six years of age. For example, one could assume an exposure frequency of 35 to 40 days per year and an ingestion of 10 g/day (this would be for less than 2% of children according to the analysis of Stanek and Calabrese in Table 4.7) to build a potential pica exposure scenario.

Table 4.9 Soil Ingestion Estimates For Use In Risk Assessment

	9-year exposure scenario	30- and 70-year exposure scenario
Soil ingestion rate	8.7 mg/kg-day	1.7 mg/kg-day

4.8 References

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